Investigations into the substitutability of conventional coatings with coatings based on renewable raw materials in graphic printing

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Abstract

The substitutability of conventional coating systems with ("green") coating systems based on renewable raw materials is being investigated with regard to the properties of graphic printing. In addition to color and rheological properties, the main focus is on technical printing properties such as abrasion resistance, static and dynamic friction, and wet block resistance. The four "green" coating systems tested show differing performance on three different substrates. Only the matte coating system proved to be fully acceptable as a substitute, while the glossy coatings tested showed only limited performance.

Keywords: substitutability, sustainable coatings, renewable raw materials, graphical printing, resistance properties, converting properties

1. Introduction and background

The term "sustainability" is a key concept of our time that is defined and interpreted in many ways. The term links numerous topics and can be described using the three pillars of ecology, economy and social affairs, which interact with their factors of ecological viability, economic efficiency and social justice (BMZ 2025).

Coating systems play a decisive role in graphic packaging printing, particularly in terms of aesthetics and their protective function for the printed image (Herzau and Dreher 2020). With an increasing focus on sustainability, there is a growing need to drive forward the transition to "holistic sustainable packaging". In addition to the use of "sustainable" fiber-based substrates, it is important to develop new printing inks and coating systems that are not only comparable in performance to conventional systems but are also environmentally friendly (Nicolay 2025).

Each coating system basically consists of four component groups - film-forming binders, additives, solvents and fillers - with different functions and properties, whose percentages vary depending on the formulation (Nanetti 2019). So-called dispersion coatings are made up of resins, waxes, film-forming aids, wetting agents, defoamers and water (Bühler et al. 2018). For fiber-based packaging materials, such as folding cartons, the coatings are applied to the substrate in the offset printing process via a coating unit or, more rarely, an inking unit. The coating unit is located downstream of the inking units in the printing press and is set up like a flexographic printing unit with features specially developed for this purpose (Stahl and Dörsam 2013).

To characterize the use of "green" coating systems compared to conventional coating systems it is necessary to consider, among other things, the physical properties of the formed coating layers. The properties of abrasion resistance as well as static and dynamic friction are discussed in the following. Based on this data, the most suitable combination of coating system and substrate can be determined for specific applications.

2. Materials and methods

Six water-based coating systems (see section 2.1) were applied to three different substrates (see section 2.2) using the flexographic printing process. The samples were examined and characterized according to their properties, including abrasion resistance as well as static and dynamic friction (see section 2.3).

2.1 Coating systems

Six water-based coating systems were considered for the study: two conventional overprint protective coatings and four "green" overprint protective coatings based on renewable raw materials, with a glossy or matte finish. The term "green" is used in a non-judgmental way to indicate a coating claimed as sustainable by the manufacturer, the bio-based or renewable content will not be discussed at this point. The coating systems were sourced from two coating manufacturers (*Weilburger Graphics*, Gerhardshofen, Germany; *Siegwerk*, Büdingen, Germany) and are described in Table 1.

Table 1: Conventional and "green" coating systems

Code	**Manufacturer**	**Coating system**	**Formulation**	**Finish**	**Appearance**
WCM	Weilburger	W34012	Conventional	Extra matte	
WCG	Weilburger	W34016	Conventional	Glossy	
WRM	Weilburger	20F 3900 Senolith	Renewable raw materials – 87%	Matte	
WRG	Weilburger	60F 3900 Senolith	Renewable raw materials – 92%	Glossy	
SRG1	Siegwerk	15-625764-4 UniNature Preprint	Renewable raw materials – 50%	Glossy	
SRG2	Siegwerk	15-024630-4 UniNature Postprint	Renewable raw materials – 23,8%	Glossy	

As shown in Table 1 in the column Appearance, the color impression of the dispersion varies depending on the formulation of the coating systems. Coating systems based on renewable raw materials show a slightly to more yellow-brownish color nuance. Objectively speaking, there is only little effect on the color impression of the packaging product, as a low layer thickness is applied and there is no direct comparison with the conventional variant in the trade or in use.
Other properties such as formulation, viscosity, drying speed and direct food contact (DFC) are not discussed further here. The application quantity is based on the manufacturer's instructions.

2.2 Substrates

The coating systems were applied to a graphic art paper (*Magno Gloss 135 g/m², Sappi, Johannesburg, South Africa*, abbreviated to "P"), a chromo board (*Performa Light 285 g/m², Stora Enso, Helsinki, Finland*, abbreviated to "GC2") and a class 2 chromo duplex board (*300 g/m², Buchmann Karton, Annweiler am Trifels, Germany*, abbreviated to "GD2").

2.3 Test procedures for printing properties

Prints, especially packaging prints, must meet a list of requirements. These requirements include composition and structure, strength, surface, optical, electrical, permeation, penetrations and sorption, printability, converting, chemical, biological, organoleptic properties and recyclability (Pollex 2013).

To characterize the different coating systems, properties like gloss, drying time, wet blocking resistance, abrasion resistance, and the static and dynamic friction of the applied coating layer were considered. These properties are included in the overall assessment. However, only the technical performance is discussed below, as this provides information about the performance, e.g. in packaging applications.

2.3.1 Abrasion resistance

The phenomenon of abrasion occurs in particular in the converting processes and in the areas of application. A Quartant abrasion tester (*Prüfbau*, Peißenberg, Germany) is used to simulate these abrasion stresses. The abrasion resistance of the applied coating layer on the different substrates is tested under predefined conditions (Pollex 2013).

Four rubbing weights with a defined mass of 600 g perform an oscillating and rotating movement on the clamping plates, whereby pairs of samples are rubbed together with a stroke rate of 300. Attention must be paid to impurities such as dust particles, which can falsify the test results.

The samples are evaluated visually under a standardized light source by using a scoring system. The scoring scheme ranges from unsatisfactory "0", with severe abrasion down to the substrate, to "10", with no visible abrasion.

2.3.2 Static and dynamic friction

Static and dynamic friction similarly display a significant role in converting processes and in the areas of application, influenced by factors such as the coating system and coating laydown, substrate structure and humidity. The test is carried out in accordance with the DIN ISO 15359:1999 standard, from which the following basic principles can be derived.

The coefficient of friction is shown by $F_\mathrm{f} = \mu F_\mathrm{N}$, where F_f is the friction force, μ is the coefficient of friction and F_N is the normal force. The coefficient μ can describe the two conditions of static or dynamic friction. The coefficient is dimensionless.

The coefficient of static friction μ_s [1] is the maximum friction force $F_\mathrm{f,max}$ between two objects when neither of the objects is moving.

$$\mu_\mathrm{s} = \frac{F_\mathrm{f,max}}{F_\mathrm{N}} \qquad [1]$$

The coefficient of dynamic friction μ_k [2] is the kinematic friction force $F_\mathrm{f,k}$ between two objects when one object slides relative to the other object, or if two objects are moving against one another.

$$\mu_\mathrm{k} = \frac{F_\mathrm{f,k}}{F_\mathrm{N}} \qquad [2]$$

A hanatek Advanced Friction Tester (*Rhopoint Instruments*, St. Leonards-on-Sea, UK) is used to simulate these static and dynamic friction stresses. The friction of the applied coating layer on the different substrates is tested under predefined conditions.

After a dwell time of three seconds, the sample pair – coated front and uncoated back of the substrate – slides along a measuring distance of 150 mm at a speed of 150 mm/min, with a defined test weight of 200 g acting on the sliding carriage. These parameters form the slip test method.

The measurement data is evaluated directly in the measuring device using this slip test method. The test results are sorted into the scoring scheme depending on the determined coefficient of friction, from unsatisfactory "0" for inconsistent results, "1" with $\mu > 0{,}56$ to "10" with $\mu < 0{,}15$.

2.3.3 Wet blocking resistance

Wet blocking resistance describes the blocking behavior of the coatings when exposed to moisture. Despite drying without blocking, the coating layer can dissolve, and, as a result, surfaces lying on top of each other can stick together. Using a block tester (*Prüfbau*, Peißenberg, Germany), test surfaces are examined with defined liquid impact and a defined contact pressure of 10 N/cm^2 (Prüfbau 2023).

The samples are evaluated visually by using a scoring system. The scoring scheme ranges from unsatisfactory “0”, with strong blocking and fiber cracking, to “10”, with no visible blocking.

3. Results and discussion

The test results of the abrasion resistance test as well as static and dynamic friction provide information about the behavior of a packaging in processes of converting, logistics and trade, up to the end customer. The evaluation includes areas printed with CMYK (1C) and coated with the respective coating system as well as areas that only show the coating application on the substrate. The evaluation is carried out according to the scoring schemes classified in chapter 2.

Due to the limited scope of this abstract, only the properties of abrasion resistance as well as static and dynamic friction are discussed in more detail. The property of wet block resistance is part of the evaluation (see section 3.3).

3.1 Abrasion resistance test results

High abrasion resistance is important in the life cycle of packaging. This means that the higher the rating, the better. Table 2 shows the scoring results of the investigated coating-substrate combinations of the abrasion resistance test.

Table 2: Abrasion resistance rating of conventional and “green“ coating systems

Substrate	WCM	WCG	WRM	WRG	SRG1	SRG2
P	8.0	6.0	8.0	7.5	4.5	5.5
GC2	7.5	6.5	7.5	7.0	3.0	7.5
GD2	7.0	3.0	7.0	2.5	1.0	4.5

The coating systems behave similarly on the substrates, so that a dependency on the surface quality can be assumed. The higher the proportion of recycled fibers in the substrate, the lower the strength of the paper and the more uneven the surface of the substrate. Accordingly, all coating systems perform worst on substrate GD2. It is also striking that the glossy coatings achieve significantly worse results than the matte coatings. One possible explanation is due to the fillers contained in the matte coatings, which on the one hand act as spacers and on the other, like a paper coating, smooth a rough surface. A smoother surface is less susceptible to abrasion, as less friction and therefore less mechanical stress is generated.

In addition, there is a difference between the coating manufacturers. The SRG coating systems perform significantly worse than the WRG coating system. Important factors in the comparison are that the evaluations were carried out at two points in time, at different locations and by different observers. To minimize the influence and deviation of the evaluation, the first samples were used for reference when evaluating the residual samples.

3.2 Static and dynamic friction test results

Frictional properties play a particularly important role in converting processes. This means that the higher the rating, the better. Table 3 shows the scoring results of the investigated coating-substrate combinations of the static and dynamic friction test. The graphical evaluation of the test data is not reported at this point.

Table 3: Static and dynamic friction rating of conventional and "green" coating systems

Substrate	WCM	WCG	WRM	WRG	SRG1	SRG2
Static friction						
P	4	7	5	6	4	5
GC2	3	8	4	7	4	7
GD2	4	7	5	7	4	6
Dynamic friction						
P	7	8	7	8	5	6
GC2	5	9	6	8	4	8
GD2	6	9	7	8	5	7

The first thing that stands out is that the matte coatings have a higher static friction. This may be due to the fillers contained in the formulation, which lead to an uneven formation of the coating laydown. Overcoming static friction therefore requires more effort. At this point it is worth mentioning that a closer look at the graphical evaluation shows unsteady force curves over the measurement distance, which means that in principle only a statement on trends is possible.
On the GC2 substrate, the matte coatings performed worse than on the other two substrates – contrary to the glossy coatings.
The glossy coating systems performed in the upper scoring range. On average, the "green" coating system WRG scored one rating point lower than the conventional coating system WCG. This also indicates a correlation with the coating formulation.

A significant difference can be seen with the SRG1 coating system. According to the manufacturer, this is formulated for a roll-to-roll application in which friction plays a subordinate role. The SRG2 coating system is formulated for sheet-fed printing and therefore provides better results that are comparable with the coating system WRG.
This example shows that it is difficult to make a general statement about good or unsatisfactory results, as the coefficient of friction takes on a different priority depending on the processing machine.

3.3 Summary test results

The final interpretation of the test results depends on the type of fiber-based packaging and its requirements. For a comprehensive evaluation, it is necessary to test other properties and resistances of the coating systems, also on different substrates. For example, the wet blocking resistance provides information about the effect of moisture on the coating layer and the resulting blocking of the product. Further consideration of a blocking test can be made during storage after the printing process up to the converting process. Other factors in the printing process relate to the processability of the coating systems, and odor pollution should be avoided. A faster drying time is advantageous for further processing and converting (Pollex 2013).

Table 4 provides a quick overview of the abrasion resistance (A), static and dynamic friction (F) and wet blocking resistance (WB) properties determined for the coating-substrate combinations.

Table 4: Summary test results of conventional and "green" coating systems depending on the substrate S, A - abrasion resistance, F - dynamic friction and WB - wet blocking resistance (with score 0 - 3 as "-", score 3.5 – 5.5 as "o", score 6 – 6.5 as "o/+", score 7 - 10 as "+")

	WCM			**WCG**			**WRM**			**WRG**			**SRG1**			**SRG2**		
S	P	GC2	GD2	P	GC2	GD2	P	GC2	GD2	P	GC2	GD2	P	GC2	GD2	P	GC2	GD2
A	+	+	+	o/+	o/+	-	+	+	+	+	+	-	o	-	-	o	+	o
F	+	o	o/+	+	+	+	+	o/+	+	+	+	+	o	o	o	o/+	+	+
WB		+	+		o/+	o		+	+		-	-	-	o	+	o	+	+

The initial question of whether it is possible to substitute conventional coating systems with "green" coating systems based on renewable raw materials can be answered as follows based on the investigation presented in Table 4:
For an application on paper, the "green" coating alternatives WRM and WRG show comparable good properties to the conventional coating systems. Both matte and glossy variants show pleasing results. The "green" coating WRM is also a good alternative for fiber-based substrates GD2.
If the fiber-based substrate GC2 is selected for packaging, the "green" coating SRG2 is recommended.

4. Conclusions

To classify coating systems, property trends regarding printability, drying behavior, gloss, mechanical resistance and friction behavior on different substrates must be determined. Based on these results, a statement can be made as to whether a coating system should be used or not. In this case, whether it is possible to substitute conventional coating systems with "green" coating systems based on renewable raw materials. The given results show that coating systems must be selected depending on the requirements of the end product and its production processes.

The further development of coating systems is a never-ending process. Formulations must be constantly adapted to process requirements, trends and raw materials. Another major influence and pressure on developments in the graphic coatings industry is exerted by regulations and laws, requirements from the market and society as well as competition between manufacturers.
As the concept of sustainability is becoming increasingly important for all stakeholders, the market for "green" coating systems is expected to grow. The first technologies are already on the market and optimizations are in the development process.
One discussion that follows on from this is the issue of raw material procurement. Supply and demand determine both availability and the associated problems of cultivation and costs. It remains to be seen whether the market and consumers are prepared to invest in more sustainability.

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